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TRANSLATION

EMISSIVITY OF DIFFUSED p-n TRANSITION

By

Yu. O. Tkhoryk

FOREIGN TECHNOLOGY DIVISION

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Emissivity of Diffused p-n Transition

by

Yu. O. Tkhoryk

The distribution of current carrier concentrations in a diffused layer of semiconductor p-n transition, obtained by the method of thermodiffusion , has been discussed. An expression for the emissivity of p.-n transition has been introduced.

Problems concerning the distribution of concentrations and currents in a flat semiconductor diode have been thoroughly investigated by K.B. Tolpigo [1], who showed, that the injection coefficient gamma depends upon the structure of p-n transition and is a function of the current, whereby with a rise in current gamma is directly proportional to the boundary value $\text{gamma}_{\text{bound}} < 1$, which is designated by values (ratios) b of mobility of the nonbasic and basic current carriers in the basic zone of the diode. Approximations of gamma to $\text{gamma}_{\text{bound}}$ are possible from top and bottom depending upon the emissivity value β. The author [1] having developed the criterion of great emissivity applied same in the zone of not too high currents gamma $\simeq 1$ for cases of linear and exponential distributions of alloying admixtures.

High β values are especially important for pulsed diodes, in which considerable base conductance modulation should be attained in order to obtain low direct resistance. But real flat pulsed diodes are ordinarily obtained by the diffusion method [2-5]; it is therefore very important to have proper criteria also for the distribution of admixtures, inherent to diffusion diodes.

This investigation is devoted to the study of emissivity of diffusion p-n transition. It is assumed, that the p-n transition is formed by the diffusion of donors in a hole semiconductor. The concentration of donors decreases with removal from the

boundary in accordance with the law $\mathrm{erfc}\sqrt{2}\frac{x}{\sqrt{Dt}}$, where x - distance from boundary, D - coefficient of diffusion of donors and t - time of diffusion annealing.

We will introduce such dimensionless designations:

$$N=\frac{n}{p_p},\quad Z=\frac{p}{p_p},\quad \nu=\frac{\mathfrak{R}}{p_p},\quad N^0=\frac{n_p}{p_p},\quad Z^0=\frac{p_p}{p_p};$$

$$B_n=\frac{j_n}{be\vartheta_p\cdot p_p\cdot\varkappa},\quad B_p=\frac{j_p}{e\vartheta_p p_p\varkappa},\quad B=\frac{j_{np}}{e\vartheta_p p_p\varkappa};$$

$$Y=\frac{Ee}{kT\varkappa};\quad A=\frac{\varepsilon\cdot\rho_0}{4\pi\tau};\quad \xi=x\varkappa.$$

Here n, p and $\mathcal{R}$ - concentrations of electrons, holes and donor respectively, P_p - equilibrium concentration of holes in the base, n_p - equilibrium concentrations of electrons in p-zone and holes in n-zone, j_n, j_p and j_{pr} - densities of electron, hole and total currents respectively, E-electric field intensity, e-electron charge; k-Boltzmann constant, T-absolute temperature; ε - dielectric permeability, γ - life span of current carriers, ρ_0-specific resistance of base at low level of injection, $\frac{1}{x}\sqrt{\frac{\varepsilon kT}{4\pi e^2 p_p}}$ - length of screening.

In conformity with the selected designations of diffusion-drift equation for electron and hole currents, the law of preservation of the number of holes and Poisson equation for the n-zone of the diode is written as follows:

$$B_n=-NY-\frac{dN}{d\xi},\qquad (1)$$

$$B_p=ZY-\frac{dZ}{d\xi},\qquad (2)$$

$$\frac{dB_p}{d\xi}=A(NZ-N^0Z^0)\simeq ANZ,\qquad (3)$$

$$\frac{dY}{d\xi}=N-Z-\nu+1.\qquad (4)$$

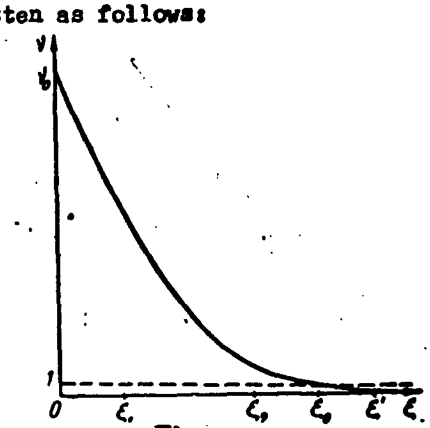

Fig.

The distribution of donor concentrations in the n-layer is expressed by

$$\nu=\nu_0\,\mathrm{erfc}\,\frac{\xi}{\alpha},$$ where $$\alpha=2\varkappa\sqrt{Dt}.$$

We will break up the n-layer into three zones (see drawing); $0<\xi<\xi_1$, $\xi_1<\xi<\xi_2$ and $\xi_2<\xi<\xi_0$, where ξ_0 corresponds to the center of p-n transition, and

xi = 0-metal contact, whereby points xi_1 and xi_2 will be selected so that at $xi < xi_1$ it will be possible to approximate the distribution of donor concentrations by the linear function, and restrict ourselves to the first member of the schedule

$$\operatorname{erfc}\frac{\xi}{\alpha} = 1 - \frac{2}{\sqrt{\pi}}\left[\frac{\xi}{\alpha} - \frac{\left(\frac{\xi}{\alpha}\right)^3}{3\cdot 1!} + \frac{\left(\frac{\xi}{\alpha}\right)^5}{5\cdot 2!} - \frac{\left(\frac{\xi}{\alpha}\right)^7}{7\cdot 3!} + \ldots\right], \qquad (6)$$

and at $xi > xi_2$ utilize the asymptotic formula

$$\operatorname{erfc}\frac{\xi}{\alpha} = \frac{\alpha\cdot e^{-\frac{\xi^2}{\alpha^2}}}{\sqrt{\pi}\cdot\xi}\left(1 - \frac{\alpha^2}{2\xi^2} + \frac{1\cdot 3\alpha^4}{4\xi^4} - \frac{1\cdot 3\cdot 5\alpha^6}{8\xi^6} + \ldots\right), \qquad (7)$$

in which it is also possible to confine ourselves to the first member; It can be shown easily that the adopted approximations offer an error, which does not exceed 5% at xi_1=Q^{4a}, and xi_2 = 3a.

In the first zone ($0 < xi < xi_1$) we will obtain a linear distribution of donor concentrations - case investigated by K.B.Tolpigo [1], the solution of which we have utilized. It has the form of

$$B_p(\xi_1) = \left[\frac{Q_+}{N(0)} + A\xi_1\right]N'(1+N'), \qquad (8)$$

where Q_+ - transparency of the contact for holes and N'=N (xi'), whereby xi' - a certain point in quasineutral p-zone.

We will now examine the zone $xi_2 < xi < xi_0$. Disregarding the volumetric charge, we will write equations (4) in form of

$$N - Z = \nu - 1. \qquad (9)$$

Differentiating (9) by xi and substituting the result in the expression for B_p-B_n, obtained by subtracting (1) from (2), we will designate the field:

$$\gamma = \frac{\frac{\nu_0}{\sqrt{\pi q}}e^{-q\xi^2}\left(2q + \frac{1}{\xi^2}\right) + B_p - B_n}{2N + 1 - \frac{\nu_0}{\sqrt{\pi q}\,\xi}e^{-q\xi^2}}, \qquad (10)$$

where $q = \frac{9}{xi_2^2}$. Since we are interested in the high emissivity criterion, it is sufficient only to consider the case of weak currents. For this we will write

$$\nu \gg \frac{|B_p - B_n|}{2q\xi + \frac{1}{\xi}}. \qquad (10a)$$

Then

$$\gamma = \frac{\frac{\nu_0}{\sqrt{\pi q}}e^{-q\xi^2}\left(2q + \frac{1}{\xi^2}\right)}{2N + 1 - \frac{\nu_0}{\sqrt{\pi q}\,\xi}e^{-q\xi^2}}. \qquad (11)$$

Substituting this expression in (2) and siregarding B_p we compare same with other terms and obtain

$$\frac{dZ}{d\xi}=\frac{Z\frac{\nu_0}{\sqrt{\pi q}}e^{-q\xi^2}\left(2q+\frac{1}{\xi^2}\right)}{2Z-1+\frac{\nu_0}{\sqrt{\pi q}\xi}e^{-q\xi^2}}. \qquad (12)$$

Solution, which is easily obtained by substituting

$$Z=yu(y),\ y=\nu-1, \quad (12a)$$

which acquires the form of

$$Z\cdot(Z-1+\nu)=NZ=\text{const}. \qquad (13)$$

This result is also in agreement with that obtained in [1] for the case of linear distribution of donor concentrations. In this way, in two boundary zones of transient layer we obtained solutions, which are in agreement. We will assume, that solution (13) can be applied also for the zone where $\xi_1 < \xi < \xi_2$, that is valid for all xi values (validity criteria of such an approximation will be obtained later on). Then

$$B_p(\xi_0)=\left[\frac{Q_+}{N(0)}+A\xi_0\right]N'(1+N'), \qquad (14)$$

hence the emissivity of p-n transition

$$\beta=\frac{\frac{N(0)}{Q_+}}{1+A\xi_0\frac{N(0)}{Q_+}}, \qquad (15)$$

which is in conformity with formula (26) of report [1].

We shall evaluate the accuracy of the made approximation.For which it was possible to write NZ = const for which it is necessary that

$$NZ\gg\left|\int_0^{\xi_0}\frac{d}{d\xi}(NZ)\,d\xi\right|. \qquad (16)$$

The value $\frac{d}{d\xi}$ (NZ^0) can be designated so. We will multiply (1) by Z, and (2) by N and compile the obtained equations. Then we will substitute in the found expression the value B_p from (3), where will be written

$$NZ=N'(1+N') \qquad (17)$$

and

$$B_n=\frac{B_p-B}{b}. \quad 17a$$

Applying (9) and (17),we will obtain

$$\int_0^{\xi_0} \frac{d}{d\xi}(NZ)\, d\xi = \frac{(b-1)AN'(1+N')}{4b}\xi_0^2 + \frac{B+(b-1)B_p(0)}{2b}\xi_0 +$$

$$+\frac{B-B_p(0)}{2b}\int_0^{\xi_0}[\sqrt{(\nu-1)^2+4N'(1+N')}-\nu]\,d\xi -$$

$$-\frac{AN'(1+N')}{2b}\int_0^{\xi_0}[\sqrt{(\nu-1)^2+4N'(1+N')}-\nu]\,\xi d\xi -$$

$$-\frac{B_p(0)}{2}\int_0^{\xi_0}[\sqrt{(\nu-1)^2+4N'(1+N')}+\nu]\,d\xi -$$

$$-\frac{AN'(1+N')}{2}\int_0^{\xi_0}[\sqrt{(\nu-1)^2+4N'(1+N')}+\nu]\,\xi d\xi. \qquad (18)$$

We will evaluate the integrals, which are included in (18). We will notice that

$$\sqrt{(\nu-1)^2+4N'(1+N')}+\nu \quad - (18\ a)$$

monotonously increasing, and

$$\sqrt{(\nu-1)^2+4N'(1+N')}-\nu \quad - (18\ b)$$

monotonously decreasing function ν, and for this are valid inequalities

$$\int_0^{\xi_0}[\sqrt{(\nu-1)^2+4N'(1+N')}-\nu]\,d\xi \leqslant [2\sqrt{N'(1+N')}-1]\,\xi_0. \qquad (19)$$

$$\int_0^{\xi_0}[\sqrt{(\nu-1)^2+4N'(1+N')}-\nu]\,\xi d\xi \leqslant [2\sqrt{N'(1+N')}-1]\,\xi_0^2. \qquad (20)$$

$$\int_0^{\xi_0}[\sqrt{(\nu-1)^2+4N'(1+N')}+\nu]\,d\xi \leqslant 2\nu_0\xi_0. \qquad (21)$$

$$\int_0^{\xi_0}[\sqrt{(\nu-1)^2+4N'(1+N')}+\nu]\,\xi d\xi \leqslant 2\nu_0\xi_0^2. \qquad (22)$$

(It is assumed that $v_o \gg 1$, $N'(1+N')$; $v(xi_o)=1$). Using the inequalities (19)-(22) we will only magnify the inequality (16). It can therefore be written that

$$NZ \gg \nu_0\,|AN'(1+N')\xi_0^2 + B_p(0)\xi_0|. \qquad (23)$$

Substituting in (23) $B_p(0)$ from (8) and writing that $\nu_o \simeq N(0)$, we will finally obtain

$$1 \gg Q_+\xi_0 + A\xi_0^2 \dot{N}(0). \qquad (24)$$

With an accuracy to constant multiples of the order of a unit of criterion (24) agrees with the analogous criterion (28) in report [1].

In addition to above statement, in the investigation was also utilized another

approximation, and it was assumed, that in the zone, which confines itself to p-n transition ($xi_2 < xi < xi_0$), the hole current can be disregarded. At gamma $\simeq$ 1 this is equivalent to the requirement of low thickness of this zone as compared with xi_2, i.e.

$$\xi_0-\xi_2 \ll \xi_2. \quad (24a)$$ ige 480

Since erfc $\frac{xi}{alpha}$ at $\frac{xi}{alpha} > 3$ decreases rapidly with a rise in xi this restriction is not actual. True, already at $xi_0 - xi_2 = 0.6$ a $\leq xi_2$ we will obtain $\vartheta_0 = 2 \cdot 10^6$, then as usually ϑ_0 does not exceed 10^4-10^5.

The criterion, that at weak currents the injection coefficient is close to one, is

$$Q_+ \xi_0 \lessgtr AN(0)\xi_0^2 \ll 1. \quad (25)$$

It can be seen easily, that criterions (24) and (25) are in practical conformity. Since we are interested only in the case of large β, we will not consider an opposite case, when these criteria are disrupted.

We have to explain at what currents is realized the condition gamma $\simeq$ 1. The proper criterion for strong currents will be

$$B \ll \beta^2 A^2. \quad (26)$$

During the realization (25)

$$\beta \simeq \frac{1}{A\xi_0}. \quad (26\ a)$$ ..page 480

Formula (26) will then be written as

$$B \ll \frac{1}{A\xi_0^2}. \quad (27)$$

Otherwise at

$$B \gg \frac{1}{A\xi_0^2} \quad (28)$$

gamma tends directly to the boundary

$$\gamma_{rp} = \frac{b}{1+b}. \quad (28a)$$

In conclusion we will mention, that, as is evident from [1] the emissivity of p-n transition in case of linear distribution of admixtures should be the higher, the greater $\frac{d\eta}{dxi}$. For the diffusion p-n transition $\frac{d\eta}{dxi}$ - variable value, which reaches max value when xi = 0. Consequently also in this case remain valid the conditions for a rise in β with a rise in $\left(\frac{d\eta}{dxi}\right)$ xi = 0. We will also point out, that because of

impossibility of accurately evaluating the value $\frac{d}{dxi}$ (NZ) in the zone $xi_1 \angle xi \angle xi_2$ the requirements of criterion (24) are, apparently, highly dependent, i.e. at other uniform conditions the emissivity of diffusion p-n transition should be much higher, than during linear distribution of admixtures.

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